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ECBC-TN-031

CHARACTERISTICS AND SAMPLING EFFICIENCIES OF TWO PERSONAL AEROSOL SAMPLERS

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July 2007

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
XX-07-2007	Final	Jan 2005 - Jun 2006

4. TITLE AND SUBTITLE
Characteristics and Sampling Efficiencies of Two Personal Aerosol Samplers

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Kesavan, Jana S. (ECBC); and Schepers, Deborah R. (MTS)

5d. PROJECT NUMBER
622384/ACB2

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
DIR, ECBC, ATTN: AMSRD-ECB-RT-TA, APG, MD 21010-5424
Mitretek Systems, Inc., 3150 Fairview Park Drive, Falls Church, VA 22042

8. PERFORMING ORGANIZATION REPORT NUMBER
ECBC-TN-031

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Characteristics and aerosol sampling efficiencies of two units of the same model Personal Aerosol Sampler (PAS-1 and PAS-2) were characterized at ECBC. These samplers were designed and manufactured by Research Center for Toxicology and Hygienic Regulation of Biopreparations at the Federal Directorate of Medical, Biological and Extreme Problems "Medbioextrem", Ministry of Health of the Russian Federation, Russia. These samplers have non-traditional wetted wall cyclones to collect and concentrate aerosols into liquid. The samplers are small, portable, and easy to use for decontamination. The sampling efficiency tests were conducted with monodisperse 0.5-, 1-, and 2.1-μm fluorescent Polystyrene Latex (PSL) microspheres, and 5.8- and 9.6-μm fluorescent oleic acid particles. The air flow rate of PAS-1 was 10 Lpm and the air flow rate of PAS-2 was 9 Lpm. The sample output volumes for PAS-1 and PAS-2 were 1.9 ± 0.5 cm^3 and 2.0 ± 0.5 cm^3, respectively. The results of PAS-1 and PAS-2 showed the highest sampling efficiency of 72.6% ± 6.8 and 77.6% for 5.8-μm particles, respectively. The power requirements of these samplers will depend on the vacuum pumps used to pull the air through the samplers.

15. SUBJECT TERMS

Aerosol samplers	Personal Aerosol Sampler	Vibrating Orifice Aerosol Generator
Aerosol	Fluorescein	Wetted Wall Cyclone

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Sandra J. Johnson
U	U	U	UL	19	19b. TELEPHONE NUMBER *(include area code)* (410) 436-2914

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PREFACE

The work described in this technical note was authorized under Project No. 622384/ACB2, Non Medical CB Defense. The work was started in January 2005 and completed in June 2006. The data are recorded in laboratory notebook 04-0060, pages 104 – 121.

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CHARACTERISTICS AND SAMPLING EFFICIENCIES OF TWO PERSONAL AEROSOL SAMPLERS

1. INTRODUCTION

This technical note is one in a continuing series of short reports intended to document and preserve the record of data from characterizing aerosol samplers. This report is not intended to be a comprehensive study or analysis. A technical note simply records a limited set of observations, offers some preliminary analysis, and, if appropriate, provides a record of the measured data to the group that provided the device. Results of more thorough studies may be found in technical reports.

Air samplers/concentrators and detectors are important in the war against terrorism and on the battlefield to detect the presence of chemical, biological, and nuclear aerosols. Samplers/concentrators and detection systems must be evaluated and their performance efficiencies determined so that suitable samplers and detectors can be used. Knowledge of equipment performance enhances the ability to protect soldiers, first responders, and the general public. An ideal aerosol concentrator should be small, portable, use minimal power, and have high concentration efficiency.

Some aerosol samplers are designed to collect bioaerosols into liquid to preserve the viability of organisms. Wetted wall samplers such as personal aerosol samplers (PAS) collect aerosols in this manner to preserve viability. In this study, the characteristics and sampling efficiencies of two units of the same model Personal Aerosol Sampler (PAS-1 and PAS-2) were characterized. The PASs were manufactured by Research Center for Toxicology and Hygienic Regulation of Biopreparations at Federal Directorate of Medical, Biological and Extreme Problems "Medbioextrem", Ministry of Health of the Russian Federation, Russia. A previous version of the sampler and its theory are described by Sigaev et al. (2006).[1] In addition, characteristics such as liquid volume and air flow rates of these samplers were also measured.

2. EQUIPMENT AND FACILITIES

2.1 Chamber.

The tests were conducted in a 3′ x 4′ x 5′ Plexiglass box (Figure 1) that was placed in the 70-m^3 Biosafety Level 1+ chamber (Figure 2) at the U.S. Army Edgewood Chemical Biological Center (ECBC). The air flow rate of the personal aerosol samplers are low (9 – 10 Lpm); therefore, the low volume Plexiglass box was used to achieve high aerosol concentrations for the sampling efficiency tests. The samplers and reference filters were placed in the Plexiglass box and a fan in the box mixed the air periodically (5 sec per min) to maintain uniform aerosol concentration in the box.

The air filtering system of the 70-m^3 chamber was used to clean the air of the Plexiglass chamber inside the 70-m^3 chamber. HEPA filters were installed at the 70-m^3 chamber

air inlet to filter the air entering the chamber to achieve very low background particle concentrations in the chamber. Similarly, HEPA filters were also installed at the exhaust port of the 70-m^3 chamber to filter particles leaving the chamber. The aerosol concentration in the 70-m^3 chamber and the Plexiglass box was reduced by exhausting chamber air through the HEPA filters and by pumping HEPA-filtered air into the chamber.

The aerosol generators were connected to the Plexiglass box to deliver the aerosol, and an APS was used to measure the particle size and concentration of the particles in the Plexiglass box. A filter port on the Plexiglass box was used to balance the pressure differences inside and outside.

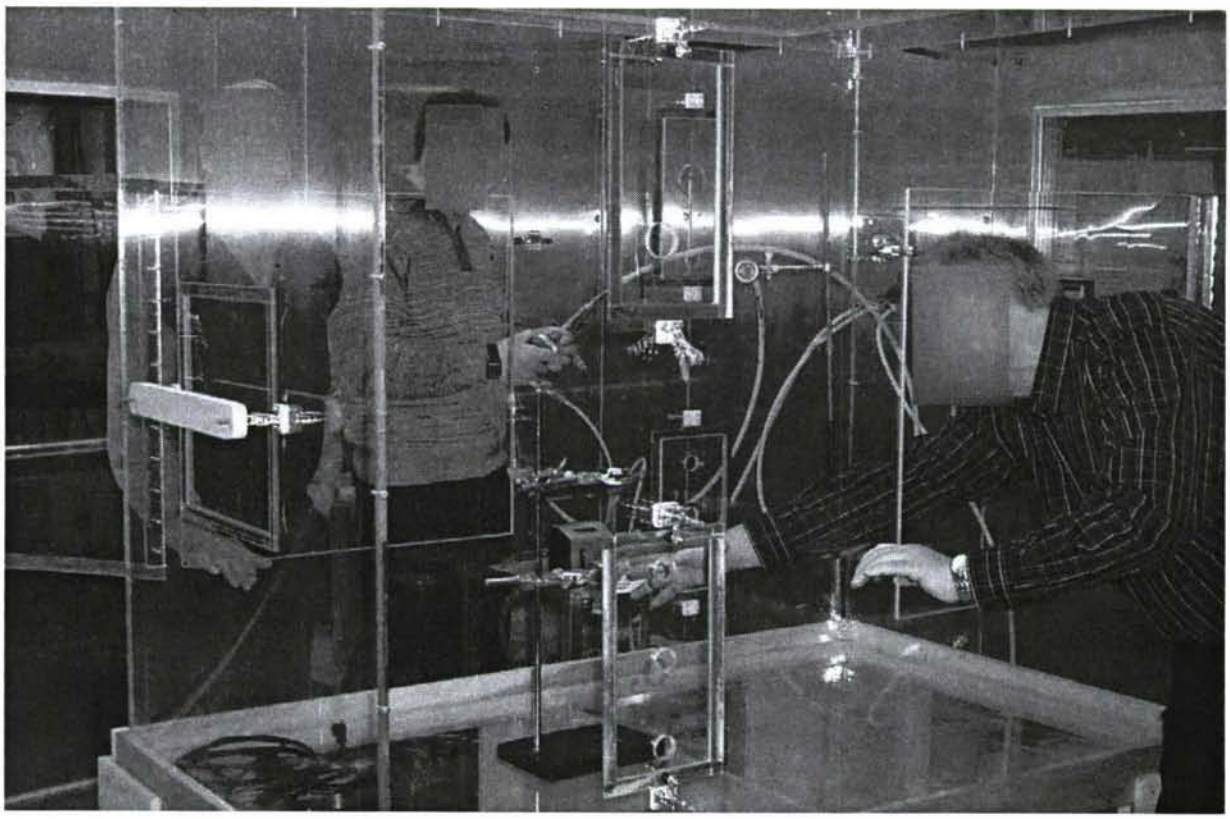

Figure 1. Picture of 3' x 4' x 5' Plexiglass Box.

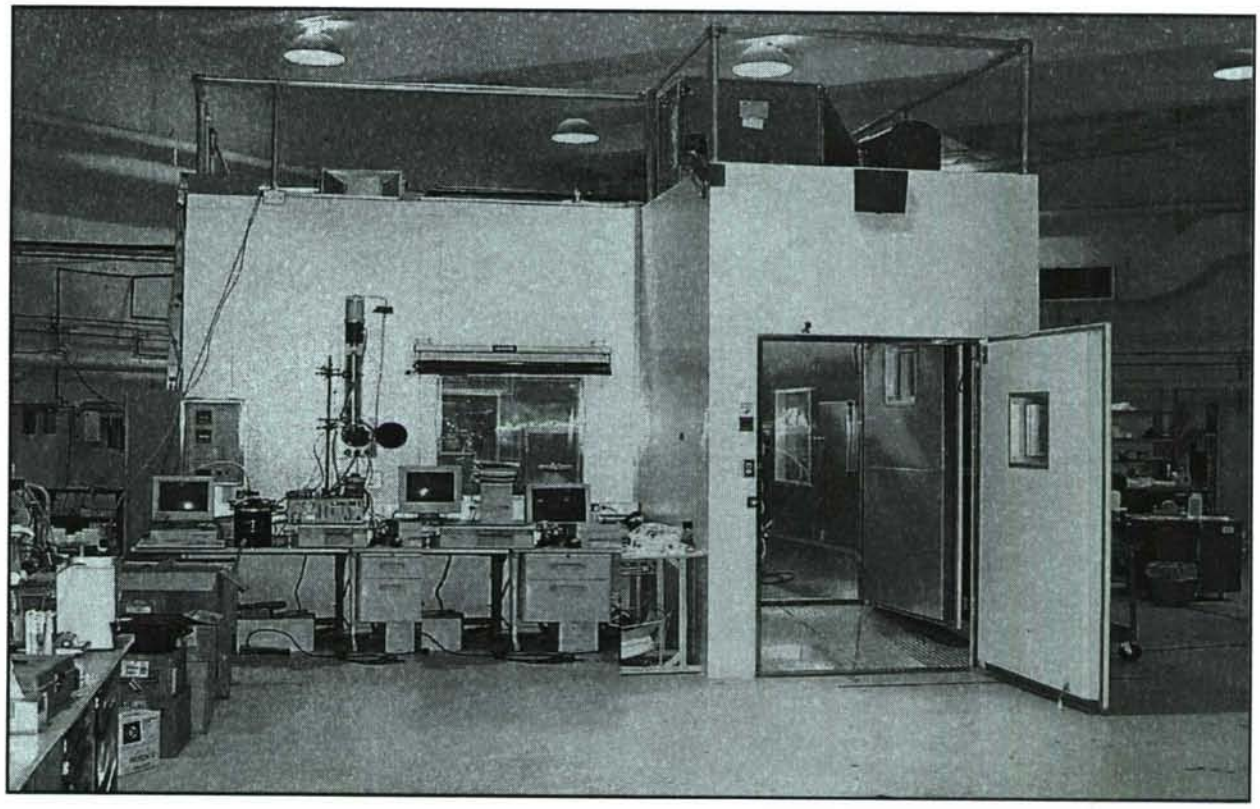

Figure 2. 70-m^3 Aerosol Chamber at ECBC.

2.2 Personal Aerosol Samplers.

The PAS is a non-traditional wetted wall horizontal cyclone that is designed to sample air at an air flow rate of 9 – 10 Lpm. This is a personal, portable sampler and a picture of the two PASs is shown in Figure 3. A more detailed picture is shown in Figure 4. The sampler characteristics are given in Table 1. Air enters the cyclone through the inlet and the low pressure at the inlet causes the sample collection liquid to be pulled into the cyclone from the sample collection cup. The air spirals through a horizontal cyclone, makes a 90° turn and exits the PAS. The diameter of the cyclone expands from the inlet to the exhaust of the cyclone. The sample collection liquid also spirals through the cyclone and drains into a funnel at the end of the cyclone. The funnel takes the liquid back to the liquid collection cup.

The collected particles are concentrated in the sample collection liquid because of the liquid recirculation. This sampler is made of stainless steel and plastic; therefore, it can be decontaminated easily by immersing in decontamination solution.

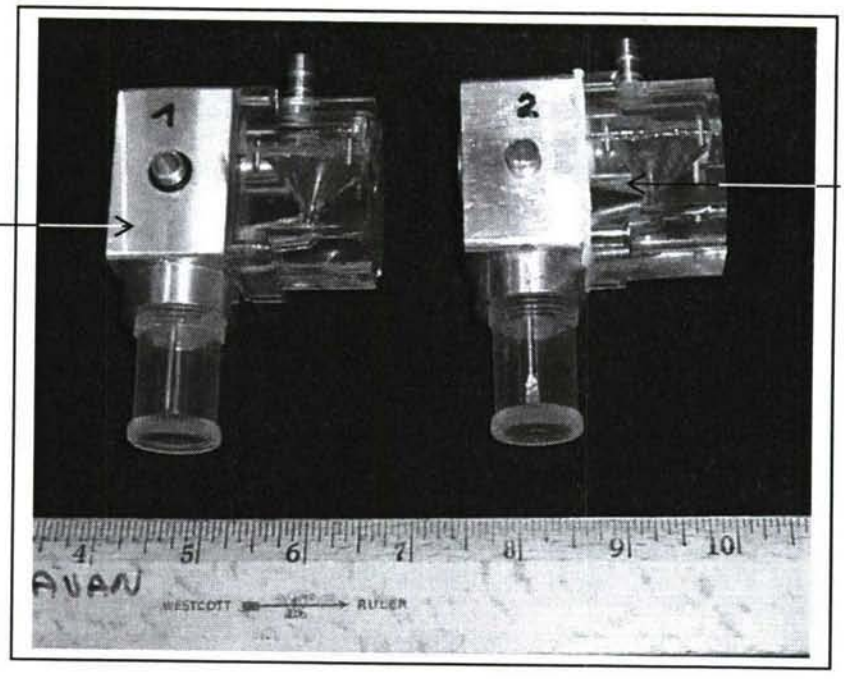

Figure 3. Picture of PAS-1 and PAS-2 Tested at ECBC.

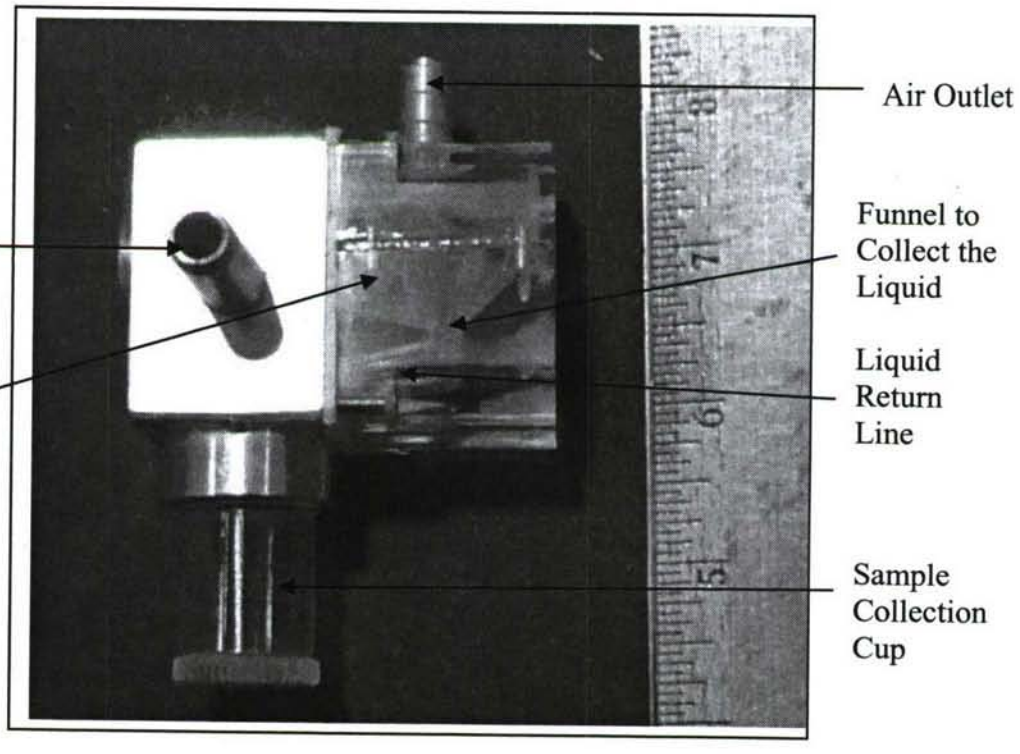

Figure 4. Detailed Picture of PAS

2.3 Sampler Characteristics.

Air flow rates of the reference filters and samplers were measured using a mass flow meter (4000 Series, TSI Inc., St. Paul, MN). The sampler characteristics are listed in Table 1.

Table 1. Characteristics of PAS-1 and PAS-2.

	PAS-1	PAS-2
Serial #	1	2
Air Flow rate, Lpm	10	9
Power, Watts	Will Depend on the Vacuum Pump Used	
Weight with cartridge (g) Reported by the manufacturer	150	150
Dimensions Reported by the manufacturer, mm	60 x 55 x 35	60 x 55 x 35
Sample Volume, cm^3	1.9 ± 0.5	2.0 ± 0.5

3. TEST PROCEDURES AND ANALYSIS

3.1 Sampling Efficiency Measurements.

The sampling efficiency tests were conducted with two kinds of aerosols and corresponding analysis methods. The first method used monodisperse 0.5-, 1-, and 2.1-μm fluorescent Polystyrene Latex (PSL) microspheres. The second method used monodisperse 5.8- and 9.6-μm fluorescent oleic acid particles. The samplers and the corresponding reference filters sampled the air simultaneously. Both the aerosol generation and analysis methods are described in detail below.

A filter was attached downstream of the samplers to capture the particles escaping the sampler. At the end of each experiment, the sample was collected and a rinse of the sampler was conducted when the sampler was pulling clean air. The rinse washed the cyclone and removed particles that did not come out with the sample. Following this, the sampler was immersed in a solution and sonicated to remove all the particles from the sampler to conduct a mass balance. The solution was deionized water for the PSL tests and recovery solution for the florescent oleic acid tests.

3.2 Polystyrene Latex Microsphere Tests.

Sampling efficiency tests were conducted with 0.5-, 1-, and 2.1-μm fluorescent PSL microspheres (Duke Scientific, Corp., Palo Alto, CA). The PSL aerosols were generated using a 24 jet Collison nebulizer and then passed through a radioactive isotope (Kr-85) neutralizer to reduce the charge on the particles. The PSL aerosol was delivered into a 3′ x 4′ x 5′ Plexiglass box that was placed in the 70-m^3 chamber. The samplers and reference filters were placed in the Plexiglass box. The aerosol was generated for a short time (approximately 5 min) and the air was mixed before sampling.

The samplers and the corresponding reference filters sampled the PSL aerosol simultaneously and for the same amount of time. Polycarbonate membrane filters (Osmonics Inc., Minnetonka, MN) were used as reference and backup filters (on the air output from each PAS) to collect the fluorescent PSL microspheres. After sampling, the samples were collected from the samplers and reference filters. The removal of particles from the membrane filter procedure consisted of placing the membrane filters into 20 mL of filtered deionized water and then hand shaking for 10 sec followed by placing on a vortex mixer for 50 sec. The hand shaking and vortexing were repeated 4 more times for a total of 5 min.

3.3 Sodium Fluorescein Tagged Oleic Acid (Fluorescent Oleic Acid) Tests.

Sampling efficiency tests were also conducted with 5.8- and 9.6-μm fluorescent oleic acid particles. The monodisperse fluorescent oleic acid particles were generated using a Vibrating Orifice Aerosol Generator (VOAG, TSI Inc., St. Paul, MN). As with the PSL tests, the generated aerosol was passed through a Kr-85 radioactive isotope neutralizer to reduce the charge on the particles before being delivered to the 3′ x 4′ x 5′ Plexiglass box. Sizes of the fluorescent oleic acid particles were determined by sampling the aerosol onto a microscope slide inserted in an impactor and then measuring the droplet size using a microscope. A microscopic picture of fluorescent oleic acid droplets on a slide is shown in Figure 5. The measured fluorescent oleic acid particle diameter was converted to an aerodynamic particle size using a spread factor (Olan-Figueroa et al., 1982) and density.[2] At the end of aerosol generation, the aerosol in the Plexiglass was mixed for one minute before sampling. The samplers and the corresponding reference filters sampled the aerosol simultaneously and for the same amount of time. Glass fiber filters (Pall Corporation, Ann Arbor, MI) were used as the reference and backup filters to collect fluorescent oleic acid particles.

The glass fiber filters were removed from the filter holders, placed into a fluorescein recovery solution, and shaken on a table rotator (Lab-Line Instruments, Inc., Melrose Park, IL) for one hour. The recovery solution used in these tests is water with a pH between 8 and 10, obtained by adding a small amount of NH_4OH (e.g., 999 mL of water with 1 mL of 14.8 N NH_4OH).

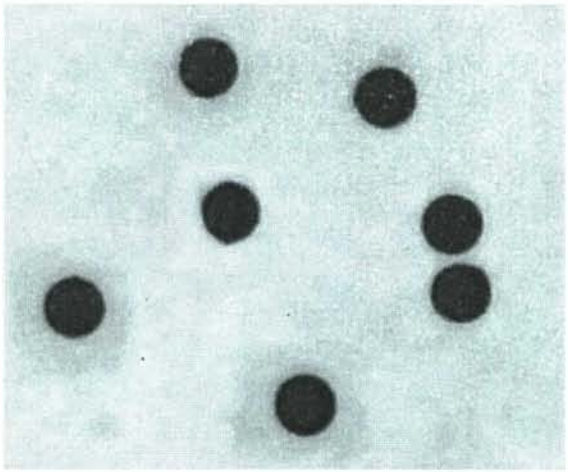

Figure 5. Microscopic Picture of 10-μm Fluorescent Oleic Acid Droplets.

Factors that affect fluorescein analysis and the removal of fluorescein from filters are described in detail by Kesavan et al. (2001).[3] The fluorescence of the solution was measured using a fluorometer (Model 450, Sequoia-Turner, Dubuque, IA). All the samples were analyzed the same day as the experiment or the next day.

3.4 Analysis.

The sampling efficiency was determined by comparing the amount of fluorescent material collected by the sampler to the reference filters. The air flow rate of the sampler and the reference filters, and the liquid volume of the samples and reference solutions were taken into consideration in the calculation.

The sampling efficiency was calculated using the following equation:

$$\text{Sampling Efficiency} = \frac{\left[\frac{(\text{fluorometer reading of sampler}) \times (\text{liquid volume})}{(\text{air flow rate})}\right]}{\left[\frac{(\text{fluorometer reading of reference filter}) \times (\text{liquid volume})}{(\text{air flow rate})}\right]} \times 100.$$

For each test, the mass balance was also conducted by rinsing the sampler to remove particles collected in the cyclone that did not come out with the sample, and immersing the sampler in liquid and sonicating it. Percent of particles in the sample, rinse, and sonicated solution compared to reference filters were calculated.

In previous experiments, the manufacturers calculated capture efficiency instead of sampling efficiency to express how well the sampler was functioning. Their "capture efficiency" is defined as particles delivered in the sample liquid divided by the sum of particles delivered in the sample liquid and particles captured by the backup filter. In this study, calculations were also conducted to determine the capture efficiency for comparison to the

sampling efficiency. Note that capture efficiency ignores the particles lost on the internal walls of the PAS and recovered in the rinse and sonicated wash.

4. RESULTS

The sampler characteristics, sampling, and capture efficiency results are summarized in Tables 1 and 2. The sampling and capture efficiency graphs for two PASs are shown in Figure 4. The results show that the highest sampling efficiency for PAS-1 and PAS-2 were 72.6% ± 6.8 and 77.6 %, respectively. Capture efficiency is significantly higher than the sampling efficiency because particles that deposited in the sampler that did not come out with the sample were not included in the calculations for capture efficiency. Sonication of the sampler after each experiment removed a significant amount of particles from the sampler and these were not included in the capture efficiency calculations.

Table 2. Average Sampling and Capture Efficiencies of PAS-1 and PAS-2.

Particle Size (μm)	Particle Type	N	Sampling Efficiency (%)		Capture Efficiency (%)	
			PAS-1	PAS-2	PAS-1	PAS-2
0.5	PSL	2*	10.1 ± 7.0**	2.4 ± 2.5	18.8 ± 13.9	5.9 ± 6.0
1.0	PSL	4	2.3 ± 2.5	5.1 ± 4.0	20.1 ± 15.2	18.6 ± 12.4
2.1	PSL	2	36.1 ± 1.2	25.3 ± 5.2	97.0 ± 0.9	96.2 ± 0.2
5.8	Oil	2	72.6 ± 6.8	77.6 ± 0	99.4 ± 0.1	99.5 ± 0
9.6	Oil	2	68.0 ± 4.2	70.1 ± 7.1	98.8 ± 1.0	99.3 ± 0.2

*Because mass balance was not conducted in the other tests, those results are not included in this Table.

**mean ± std dev.

Table 3 shows the percent of particles in the sample, backup filter, rinse, and sonicated solution compared to the reference filter. A majority of the particles came out with the sonication of the sampler for small PSL tests. On the other hand, a majority of the particles came out with the sample for the fluorescent oleic acid tests. Fluorescent oleic acid particles were larger and are soluble in recovery solution.

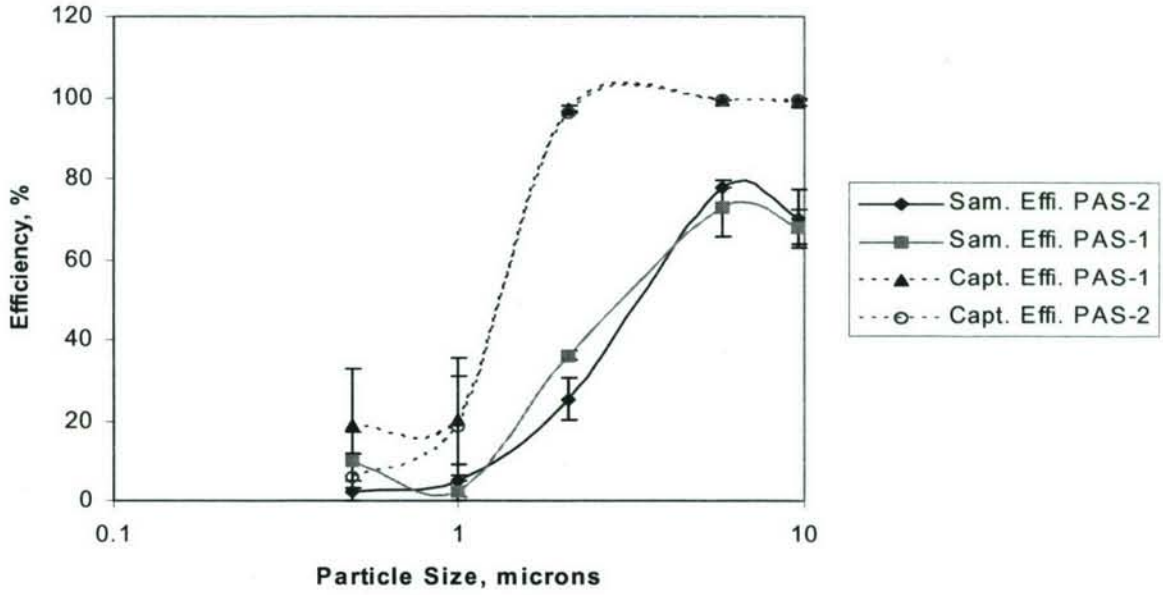

Figure 6. Sampling and Capture Efficiencies of PAS-1 and PAS-2.

Table 3. Percent Particles Recovered from Sample, Backup Filter, Rinse, and Sonication Compared to Reference Filters.

		0.5 μm	**1 μm**	**2.1 μm**	**5.8 μm**	**9.6 μm**
PAS-1	Sample	10.1 ± 7.0	2.3 ± 2.5	36.1 ± 1.2	72.6 ± 6.8	68.0 ± 4.2
	Backup Filter	44.8 ± 10.2	7.3 ± 1.0	1.1 ± 0.4	0.4 ± 0	0.8 ± 0.6
	Rinse	1.6 ± 1.0	1.3 ± 0.5	6.1 ± 1.0	11.4 ± 1.9	14.7 ± 4.7
	Sonication	55.7 ± 4.4	77.5 ± 13.5	69.5 ± 12.7	9.5 ± 4.3	16.1 ± 5.6
	TOTAL	**112.2 ± 6.6**	**88.3 ± 11.6**	**112.9 ± 13.3**	**94.0 ± 4.3**	**99.5 ± 13.8**
PAS-2	Sample	2.4 ± 2.5	5.1 ± 4.0	25.3 ± 5.2	77.6 ± 0	70.1 ± 7.1
	Backup Filter	36.3 ± 0.5	19.8 ± 0.9	1.0 ± 0.3	1.4 ± 1.4	0.5 ± 0.1
	Rinse	5.0 ± 2.3	4.0 ± 2.1	14.4 ± 1.6	14.6 ± 0.6	12.0 ± 2.6
	Sonication	63.8 ± 0.8	61.3 ± 13.8	68.4 ± 2.6	14.5 ± 2.2	23.1 ± 2.5
	TOTAL	**107.5 ± 0.1**	**90.2 ± 16.6**	**108.8 ± 6.5**	**105.1 ± 0**	**105.7 ± 2.0**

5. DISCUSSION

Characteristics and sampling efficiencies of two personal aerosol samplers (PAS-1 and PAS-2) were determined at ECBC. These samplers were only available for one week of testing. Therefore, the particle sizes and number of tests conducted were limited. Sampling efficiency was determined using 0.5-, 1-, and 2.1-μm PSL microspheres and 5.8- and 9.6-μm oleic acid particles. Both samplers had similar sampling efficiency curves. The highest sampling efficiency for PAS-1 and PAS-2 were 72.6 % ± 6.8 and 77.6 % for 5.8-μm particles, respectively.

The manufacturer of the sampler calculated the capture efficiency to describe the function of the sampler while ECBC calculated sampling efficiency. Sampling efficiency is defined as the amount of particles delivered in the sample divided by the amount of particles recovered from the reference filters. Capture efficiency is defined as particles delivered in the sample divided by the sum of particles delivered in the sample and the particles recovered from the backup filter. Sampling efficiency is believed to better describe the function of the sampler because it quantifies the amount of particles collected and delivered in the sample. Tests at ECBC showed significant amounts of particles in the rinse of the cyclone and sonicated solution, and these are not included in the capture efficiency calculations. Capture efficiency is close to 100% for 2.1-μm particles and higher sizes, whereas sampling efficiency is approximately 72 – 78% at the peak.

This sampler has liquid recirculation to concentrate the collected particles; however, liquid recirculation may cause evaporation and reaerosolization. During this testing, approximately 2 cm^3 of sample output were gathered after 10 min of sampling.

Table 3 shows the percent of particles in the sample, backup filter, rinse, and sonicated solution. A majority of the particles came out with the sonication for the PSL tests and a majority of particles came out with the sample in the fluorescent oleic acid tests. Fluorescent oleic acid particles were larger and soluble in recovery solution. From these results, it is apparent that the PSL particles are sticking to the sampler wall and not getting out with the sample or the rinse. Future tests should use water soluble particles to test this hypothesis. In addition, Table 3 shows that these samplers perform much better if they are sonicated after each test. Care must be taken when this sampler is used repeatedly without sonicating, because significant carryover into the next sample is to be expected.

6. CONCLUSIONS

Characteristics and sampling efficiencies of two personal aerosol samplers (PAS-1 and PAS-2) were determined at ECBC. These samplers were only available for one week of testing. Therefore, the particle sizes and number of tests conducted were limited. Sampling efficiency was determined using 0.5-, 1- and 2.1-μm PSL microspheres and 5.8- and 9.6-μm oleic acid particles. Both samplers had similar sampling efficiency curves. The highest sampling efficiency for PAS-1 and PAS-2 were 72.6 % ± 6.8 and 77.6 % for 5.8-μm particles, respectively. Most of the particles came out with the sample for the fluorescent oleic acid tests

and most of the particles came out with the sonication for the PSL tests. It is likely that the PSL particles are sticking to the sampler and future tests should test this hypothesis.

Many samplers are characterized at ECBC and the results are published in technical notes. When considering a sampler for an application, the decision should include information on sampling efficiency, concentration factor, sampler size, weight, air flow, pressure drop (not measured in this study), and power consumption. Readers are advised that that these samplers may be modified and/or improved based on the tests conducted at ECBC, and may be further improved as new technology becomes available. Therefore, a modified or improved sampler may have very different characteristics than those presented in this report.

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